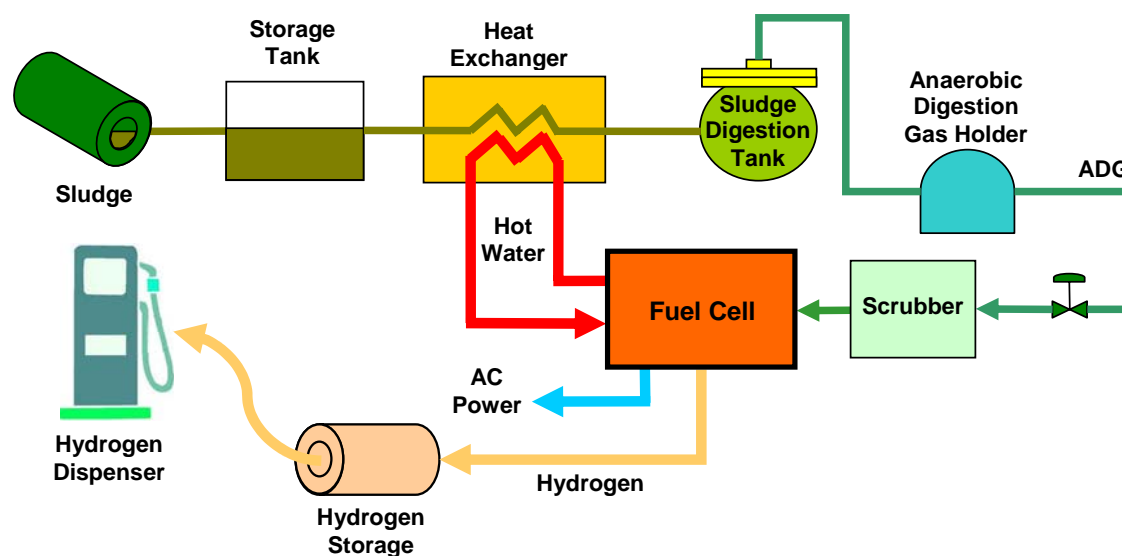US Army Corps
of Engineers®
Engineer Research and
Development Center

Waste-to-Energy ECIP (Energy Conservation Investment Program) Project

Volume I: An Analysis of Hydrogen Infrastructure Fuel Cell Technology

Gonzalo Perez, Robert Neathammer, Franklin H. Holcomb,
Roch A. Ducey, Byung J. Kim, and Fred Louis

April 2006

Waste-to-Energy ECIP (Energy Conservation Investment Program) Project

Volume I: An Analysis of Hydrogen Infrastructure Fuel Cell Technology

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Draft Report

Abstract: Volume I of this work represents a preliminary analysis of the economics from an anaerobic sludge digester Wastewater Treatment Plant (WWTP) at a military installation integrated with a fuel cell with hydrogen production capabilities. The waste-to-energy, hydrogen production/infrastructure development, fuel cell system (WTE-H2-FC) was submitted for FY06 Energy Conservation Investment Program (ECIP) funding based on the estimated Savings to Investment Ratio (SIR) range of $1.5 - 2$, and an estimated Simple Payback Period of 8+ years. Volume II of this project will include a more detailed analysis that will validate the assumptions made in Volume I, and produce a planning and design document to be used to implement the WTE-H2-FC system. This analysis considered Army installations, future analyses of the application of this technology may include Air Force and Navy bases.

Executive Summary

The Energy Conservation Investment Program (ECIP) is a subset of the Military Construction (MILCON) program specifically designed for energy saving projects for facilities. To fully utilize the ECIP program, the Construction Engineering Research Laboratory (CERL) wished to investigate the feasibility of integrating waste-to-energy technology, hydrogen production/infrastructure development, and fuel cell technology (WTE-H_2-FC), into a project that could be implemented under the Energy Conservation Investment Program (ECIP). This study analyzes the feasibility of integrating the WTE-H_2-FC technology into the ECIP Program.

The different components of the WTE-H_2-FC technology have been successfully applied before in the United States and other countries to tap into a renewable source of energy focusing on anaerobic sludge digesters at wastewater treatment plants (WWTPs). Six U.S. Army installations were considered as possible candidates to take advantage of this technology. Fort Stewart was selected as the most appropriate installation due to the size of its anaerobic digester and the support of its leadership. The feasibility analysis of two alternative designs showed that the WWTP at Fort Stewart produces enough methane to benefit from the implementation of this technology. Furthermore, the economic analysis showed that Fort Stewart could save $2.75M over 20 years by implementing the WTE-H_2-FC. Finally, the WTE-H_2-FC technology will permit Fort Stewart to use a renewable energy source to annually save the Army 1,150,000 kWh of electricity, 1,180,800 kWh of natural gas, and 291,600 kWh of hydrogen.

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Unit Conversion Factors

Multiply	By	To Obtain
British thermal units (International Table)	1,055.056	joules
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
inch-pounds (force)	0.1129848	Newton meters

1 Introduction

Background

The Energy Conservation Investment Program (ECIP) is a subset of the Military Construction (MILCON) program specifically designed for energy saving projects for facilities. ECIP is used to fund new energy efficient systems or to improve the energy efficiency of existing facilities. ECIP projects also assist Army installations in modernizing infrastructure, reducing electric utility demand, and improving energy flexibility. This program gives higher priority to projects that support renewable energy flexibility.

To fully utilize the ECIP program, the Construction Engineering Research Laboratory (CERL) wished to investigate the feasibility of integrating waste-to-energy technology, hydrogen production/infrastructure development, and fuel cell technology (WTE-H_2-FC), into a project that could be implemented under ECIP. The result of the feasibility study includes the drafting of a full project proposal following the format and guidance of the military construction 1391 project proposal process.

Objective

The objective of this work was to analyze and document the feasibility of developing the WTE-H_2-FC technology at an anaerobic sludge digester at an installation wastewater treatment plant (WWTP), using the ECIP program.

Approach

The feasibility analysis and its corresponding 1391 documentation were completed in three steps:

1. Identification of Army installations that can benefit from the WTE-H_2-FC technology.
2. Development of a preliminary conceptual design encompassing WTE-H_2-FC.
3. Identification of the Army installation where the WTE-H_2-FC project has the greatest potential for success.

Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) through URLs:

http://www.cecer.army.mil

http://www.dodfuelcell.com

2   Description of Technology

Step 1. Identification of Potential Army Installations

PERTAN Group personnel met with CERL researchers, who provided a list of Army installations with WWTPs and their capacities. Six installations were selected from the list to gather further information on their suitability to house and profit from WTE-H_2-FC technology. Factors considered for selecting the candidate installation were: Plant Ownership, Anaerobic Digester Capacity, Current Flow, and Leadership Support (Table 1).

The PERTAN Group also reviewed relevant papers and publications to estimate the amount of energy available in a wastewater treatment plant. The review provided the following conversion factors:

- Typically, Anaerobic Digester Gas (ADG) is composed of 60 to 65 percent methane and has a lower heating value (LHV) of 550 to 650 BTU per Cubic Foot (CF). This analysis assumes a heating value of 600 BTU/CF (Vik 2003).
- The amount of Anaerobic Digester Gas (ADG) produced per day is a function of the Millions of Gallons of water treated per Day (MGD), the amount of organics contained, and the time the sludge stays in the digester. A regression analysis on the results of a survey of 60 Water Treatment Plants (WTP) with anaerobic digester in Wisconsin shows that the amount of ADG, in Cubic Feet per Day (CF/Day), produced can be modeled as follows:

    ADG (CF/Day) = 12,321 x MGD − 3,700   Eq 1

    Appendix A describes this model more completely.

Step 2. Development of a WTE-H_2-FC Conceptual Design

The recovery of anaerobic digester gas to produce electricity is becoming common practice in large WWTPs in the United States and in other countries. Most of those plants generate the electricity using either an engine-generator set or a fuel cell. The most popular prime movers in the engine-generator configuration are internal-combustion engines and micro turbines. One fuel cell used in these applications is the United Technologies Corporation (UTC) PC25 200 kW Phosphoric Acid Fuel Cell (PAFC) (Adolph and Saure 2002). Figure 1 shows a fuel cell using anaerobic digester gas to produce electricity.

Table 1. Installation selection decision table.

Army Installation	Sewer Plant Ownership	WWTP Capacity	POC	Leaders Support
Fort Stewart, GA	Army/City	Designed for 9 Mg/day Permit for 7.5 Mg/day Current flow > 5 Mg/day	Fred Louis 912.767.5034 Denis Kelly 912.767.5027	Yes
Fort Campbell, KY	Privatized		Dwayne Smith 270.798.5652	
Fort Carson, CO	Army	Aerobic Process; No methane produced	Don Fuhrman 719.526.3415 Dan Golden 719.491.8596	Yes
Fort Lewis, WA	In the process of privatization. BRAC postponed it. Bids may go out December 2006	Designed for 7 Mg/day Current flow>3.5 Mg/day	Bernadette Rose 253.966.1792 Steve Glover 253.966.1788	Yes
Fort Hood, TX	No water treatment plant			
Fort Dix, NJ	In the process of privatizing the plant. Bidding is finished and the winner will be announced soon.		Radames Cales 609.562.6687 Steve Whitmore 609.562.4954	No, It will interfere with privatization process
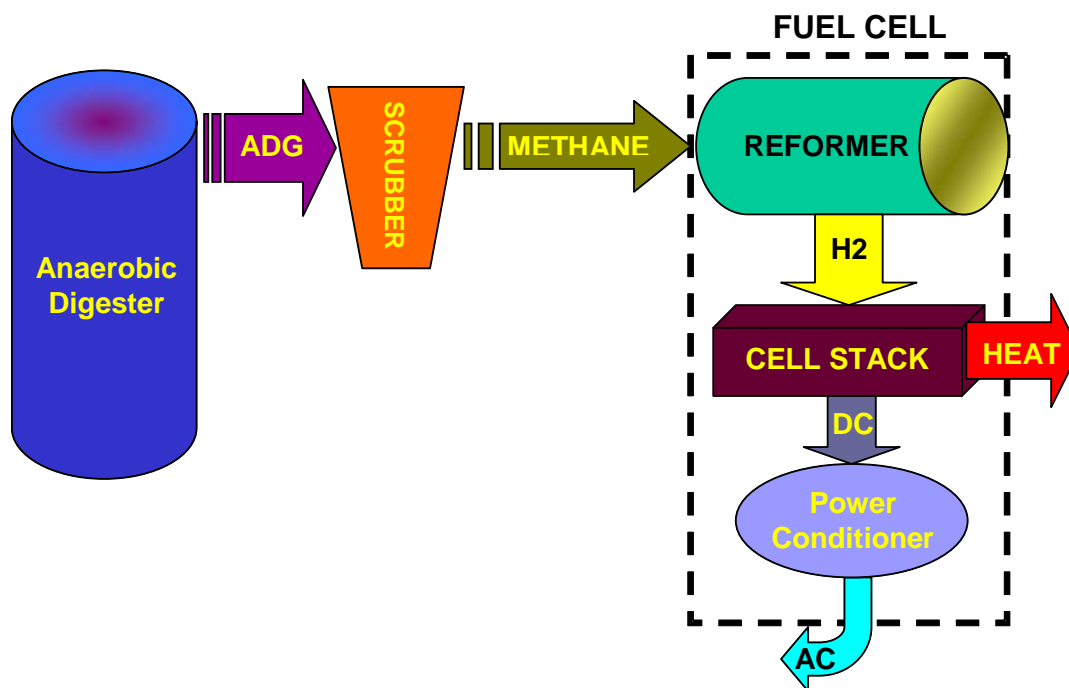
Figure 1. Components of a fuel cell using anaerobic digester gas.

PERTAN personnel reviewed several technical reports describing the application of the PC25 fuel cell in water treatment plants. That review provided the following design parameters:

- The PC25 fuel cell consumes natural gas and produces both electricity and hot water. The PC25 power plant rating is 200 kW of electricity and 205 kW of hot water. The efficiency of the electricity generation effect (Electric Efficiency) is usually around 45 percent of the energy content of the natural gas consumed. The efficiency of the heat generation effect (Thermal Efficiency) is usually around 50 percent.
- The anaerobic digester gas contains CO_2, moisture, and other undesirable particles that have to be removed before it can be used in the fuel cell. This scrubbing operation consumes energy and has the effect of reducing both the electric efficiency and the heating efficiency of the fuel cell. For this analysis, the electric efficiency of the fuel cell is considered to be 37 percent and the heating efficiency 40 percent.
- The three main components of a PC25 fuel cell are: gas reformer, cell stack, and power conditioner. The gas reformer converts the methane into hydrogen. The cell stack converts the hydrogen into Direct Current (DC) and hot water. The electric power conditioner converts the DC into usable Alternating Current (AC). The three main components of the commercially available PC25 are designed to work as a single power plant that consumes all the hydrogen it produces without any intermediate storage between the reformer and the stacks.
- To be able to use the hydrogen outside the fuel cell for a purpose other than producing electricity in the stacks requires some modifications to the fuel cell. First, the hydrogen line between the reformer and the stacks must be tapped properly and a regulating valve mechanism and control added to divert the hydrogen away from the stacks. Second, the controls of the fuel cell have to be reprogrammed so that the reformer produces more hydrogen than the amount used in the stack. Third, an external hydrogen storage system must be added to the installation and connected to the tapped hydrogen line. Finally, both controls (the fuel cell and the hydrogen storage controls) have to be integrated so that both major components work together as a system.

At the time of this analysis, PERTAN Group personnel were unable to find a commercially available system as the one described above. However, LOGAN Energy provided PERTAN with an existing conceptual design for such a system named HyCoGen (Logan Energy 2005). Although the HyCoGen conceptual design has not yet been built, its major components (the fuel cell and the hydrogen storage) are both commercially available.

Another way to provide all the functionalities required by the WTE-H_2-FC concept without re-engineering the existing PC25 is to add an off-the-shelf hydrogen refueling unit together with an off-the-shelf natural gas reformer (Figure 3). The main advantage of this alternative is that the PC25 does not have to be re-engineered. The main disadvantage is that it contains two reformers instead of only one. However, the redundancy of the second reformer increases the reliability of the refueling station since it can work even when the fuel cell is not operating.
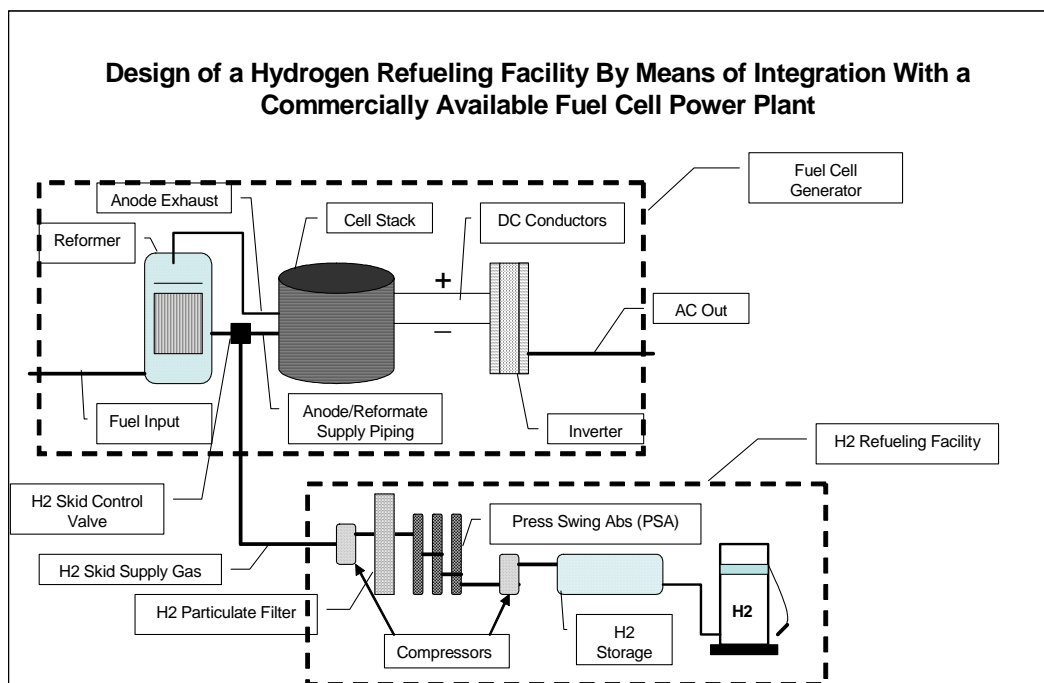
Figure 2. LOGAN Energy's HyCoGen design courtesy of LOGAN Energy.
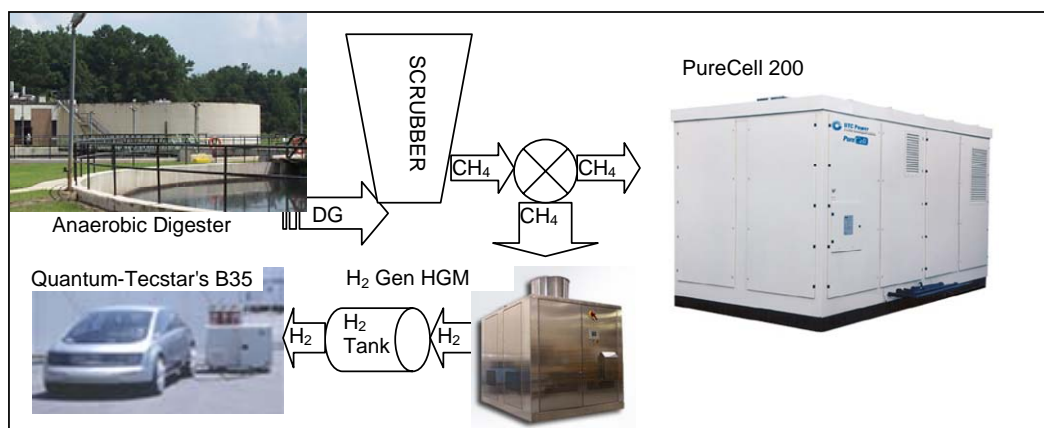
Figure 3. Off-the-shelf WTE-H_2-FC.

Step 3. Identification of the Army installation where the WTE-H₂-FC project has the greatest potential for success

Fort Stewart was selected from the six candidate installations as the preferable location for three reasons:

1. It was the installation with the largest through flow (more than 5 MGD).
2. The Energy Manager was highly supportive of the program.
3. The Army owns the land on which the plant is located and where the FC will be located.

The PERTAN Group personnel visited the plant to check the feasibility of the project and met with the plant operator and the Energy Manager of the installation. In addition, PERTAN personnel obtained economic data to be used in the 1391 documentation process.

Feasibility Analysis

The purpose of this analysis is to determine if the Fort Stewart WWTP produces enough digester gas to support the use of the PC25 fuel cell. In addition, this analysis will determine the expected outputs derived from the use of the plant. The results from this analysis will be used to support the assumption necessary to carry the Economic Analysis required by the ECIP program.

Currently, the WWTP only uses a portion of the anaerobic digester gas to warm up the sludge in the digester. The rest of the gas was burned in an open flame. At the time of the visit, the plant did not have records of the amount of ADG produced in the digester. To determine if the plant, with its current flow of 5 MGD, could generate enough digester gas to support the operation of a PC25 200 kW plant, The PERTAN Group estimated the amount of gas and its energy content as follows:

- *CF/Day of anaerobic gas*: Substituting the 5 million gallons of daily flow at Fort Stewart for MGD in Eq. 1, provides the daily anaerobic gas production in CF/Day

    ADG = 12,321 x MGD − 3,700 = 12,321 x 5 − 3,700 = 57,905 CF/Day

- *Energy content in BTU/day*: Since 1 CF of ADG contains 600 BTU of energy, the energy content of the gas is:

    Energy Content = 600 BTU/CF x 57,905 CF/Day = 34,743,000 BTU/Day

- *Power Capacity of the treatment plant in BTU/hour*: 1 BTU/Day =
  1/24 BTU/Hour

  Power Capacity = 34,743,000 BTU/Day x 1/24 Day/Hour = 1,447,625 BTU/Hour

- *Power Capacity of the treatment plant in Watts*: 1 BTU/Hour =
  0.2929 W

  Plant Capacity = 1,447,625 BTU/Hour x 0.2929 W/(BTU/Hour) = 424,009 W

- *Power Capacity of the treatment plant in kW*: 1,000 W = 1 kW

  Plant Capacity = 424,009 W x 1/1,000 (kW/W) = 424 kW

- *Electric power generating capacity of the ADG using a PC25*: As it
  was established earlier in this analysis, the PC25 has an electric effi-
  ciency of 37 percent when used to generate electricity using ADG.

  Electric Power Generation Capacity = 424 kW x 37% = 157 kW

In other words, the amount of ADG generated at the WWTP contains
enough energy to sustain the PC25 generating electricity at least at 75 per-
cent capacity, 24 hours a day, 7 days a week. Moreover, since the installa-
tion outlined above can store some amounts of ADG and/or of H_2, the
PC25 could also work at 100 percent capacity during 75 percent of the
time. This also means that the amount of ADG produced contains enough
energy to sustain the PC25 power plant working at full capacity (200 kW)
18 hours a day 7 days a week.

From those results, and after considering the actual rate schedule of Geor-
gia Power, the best schedule of operations is considered to be 16 hours of
electric and hot water production at 200 kW and 205 kW respectively, and
2 hours of only hydrogen production.

Economic Analysis

The ECIP guidance (AEP 2006) requires that a Life Cycle Cost (LCC)
Analysis be included with the DD 1391 project documentation submittal.
(Appendix B includes suggested language.) Moreover, the guidance
strongly suggests using the National Institute of Standards and Technolo-
gies (NIST) Building Life Cycle Cost (BLCC) Computer Program to per-
form the analysis (cf. Appendix C). That analysis compares the benefits
derived from the use of the WTE-H_2-FC with the different costs incurred
during its procurement, installation, and operation. The three benefits of
operating the proposed WTE-H_2-FC are the generation of electricity, hot
water, and hydrogen.

To estimate the benefits of the WTE-H_2-FC project to Fort Stewart, this
analysis assumes that the PC25 works 16 hours a day, 7 days a week, gen-

erating electricity and hot water at full capacity. For the other 2 hours a day, 7 days a week, of remaining capacity, the analysis assumes that the PC25 is generating mostly hydrogen with the rest of the plant generating just enough electricity and hot water to keep the reformer operational.

Electric Savings

Different energy savings are entered differently into BLCC for each energy type. The electricity savings are entered by estimating the annual energy in kWh/year and the cost of the kWh to the installation in $/kWh. The hot water savings and the hydrogen savings are each entered as an annual savings in $/year.

The annual electricity generated by the plant in kWh is estimated thus:

Annual Electricity = 200 kW x 16 hrs/day x 360 days/year = 1,150,000 kWh

The cost of electricity to the installation 2 years from now was estimated at $0.10/kWh. That estimate reflects the current upward trend in the cost of electricity nationwide.

Hot Water Savings

The savings from hot water are estimated by first estimating the amount of heat generated, second, estimating the amount of natural gas required to generate that amount of heat, and then estimating the cost of the natural gas to the installation.

- *Amount of heat generated as hot water in 1 year of operation*: When the PC25 produces 200 kW of electricity, it also produces 205 kW of hot water. Assuming 16 hours a day 7 days a week of operation, the amount of heat in kWh is:

    Heat Generated Annually = 205 kW x 16 hours/day x 360 days/year = 1,180,800 kWh

- *Amount of natural gas required to produce that amount of hot water in kWh*: If the above hot water were going to be produced with a natural gas domestic hot water heater with an Efficiency Factor (EF) of 0.6, the amount of gas in kWh would be:

    Amount of Natural Gas = 1,180,800 kWh /0.6 = 1,968,000 kWh

- *Cost of the natural gas to produce the above hot water*: This analysis assumes that the cost of natural gas to the installation is $ 0.60 per Therm (1 Therm = 29.3 kWh):

    Annual Cost of Natural Gas = 1,968,000 kWh x 1/29.3 Therm/kWh x $0.6/Therm
    Annual cost of natural gas = $40,300

However, not all the hot water produced by the PC25 may be useful to the installation. Moreover, the hot water coming from the PC25 may need a heat exchanger to be used as domestic hot water. To account for that eventuality, this analysis assumes that only ¾ of the potential savings from hot water production will actually materialize. In other words, this analysis assumes that the annual saving from the production of hot water is $30,000/year.

Hydrogen Savings

Savings from generating hydrogen at the installation are estimated by first estimating the amount of hydrogen generated, and then by estimating the cost to the installation from buying that much hydrogen.

- *Maximum amount of hydrogen generated in 1 year*: As explained earlier, this analysis assumes that the plant is generating hydrogen 2 hours a day, 7 days a week at full capacity. The maximum capacity of the PC25 is 405 kW (200kW + 205kW). During those 2 hours 7 days a week, the plant is capable of generating:

    Hydrogen Generated = 405kW x 2 h/day x 360 days/Year = 291,600 kWh/year

    Since 1 kWh = 3,413 BTU, and since H_2 contains 267.5 BTU per SCF, the maximum volume of H_2 generated in 1 year is:

    H_2 Generated = 291,600 kWh/year x 3,413 BTU/kWh ÷ 267.5 BTU/SCF
    H_2 Generated = 3,720,489 SCF/year

- Cost of H_2 to the installation in $/year: If the installation were to buy that amount of H_2 and did not have any storage facility to buy in bulk, it would have to buy it in regular cylinders and have it delivered there. Under those circumstances, the cost per cylinder containing 200 SCF of H_2 is $12.50. Then, the annual savings to the installation for producing all that H_2 would be:

    H_2 Savings/year = (3,720,489 SCF/year ÷ 200 SCF/Cylinder) x $12.50/Cylinder
    Maximum H_2 Savings = $232,531/year

However, for all those savings to materialize, the installation would have to be able to use all the H_2 produced regularly. Since that may not always be the case, this analysis considers only $120,000/year of savings which is approximately half of the estimated maximum annual savings.

Construction Cost

The construction cost for the WTE-H_2-FC was roughly estimated at $1,500,000. That figure was estimated in two ways. First, LOGAN Energy

estimated their cost to implement their HyCoGen concept described in Figure 2. Second, PERTAN estimated the cost of procuring the different components of the off-the-self alternative described in Figure 3. Both estimates were fairly similar.

Recurring Maintenance Cost

The annual maintenance cost was estimated at $40,000/year.

Non-Annual Recurring Maintenance

This is the cost of replacing the stacks of the fuel cells every 10 years. This cost was estimated at $400,000 every 10 years.

Results of the Economic Analysis

The beneficial life of the project is estimated to be 20 years. The economic analysis shows that the benefits to Fort Stewart from using WTE-H_2-FC technology for those 20 years are:

- First year savings of: $207,678
- Simple payback period of less that 8 Years: 7.6 Years
- Total discounted savings of: $2,747,498
- Saving-to-investment ratio (SIR) of: 1.74
- Adjusted Internal Rate of Return (AIRR) of: 5.54 percent.

3   Conclusions

The different components of the WTE-H$_2$-FC technology have been suc-
cessfully applied before in the United States and other countries to tap into
a renewable source of energy. This study concluded that, of the six U.S.
Army installations considered as candidates, Fort Stewart was the most
appropriate installation for application of this technology.

A review of the anaerobic sludge digesters at the troop installation WWTPs
showed that the size of the Fort Stewart anaerobic sludge digester was ap-
propriate for a WTE-H2-FC technology application. A feasibility analysis
of two alternative designs showed that the WTTP at Fort Stewart produces
enough methane to benefit from the implementation of this technology.
Furthermore, an economic analysis showed that Fort Stewart could save
$2.75M over 20 years by implementing the WTE-H$_2$-FC. Finally, the WTE-
H$_2$-FC technology will permit Fort Stewart to use a renewable energy
source to save the Army annually 1,150,000 kWh of electricity, 1,180,800
kWh of natural gas, and 291,600 kWh of hydrogen. These factors, along
with the expressed support of Fort Stewart's leadership combined to make
this installation the candidate of choice.

This analysis considered Army installations, future analyses of the applica-
tion of this technology may include Air Force and Navy bases.

4   Recommendations

This study recommends that the feasibility analyses presented in this re-
port be further investigated in a detailed planning and design effort before
Fort Stewart commits to this initiative. Specific issues which should be
addressed and refined in the planning and design phase include the fol-
lowing:

1. ***Confirmation of estimated parameters.***
   a. *Amount of anaerobic digester gas (ADG) available.*
      Chapter 2 (page 4) estimated that the Wastewater Treatment Plant
      (WWTP) at Fort Stewart produced approximately 58,000 CF/Day
      of ADG, based on literature data from 60 Water Treatment Plants
      (WTPs) in Wisconsin. It would be helpful to validate this estimate
      by obtaining a sample measurement of the ADG produced at Fort
      Stewart.
   b. *Methane content of ADG.*
      Chapter 2 (page 4) estimated that the methane content of the ADG
      produced at the WWTP at Fort Stewart yields approximately 600
      BTU/CF, again based on literature data from 60 WTPs in Wiscon-
      sin. It would be helpful to analyze an actual sample of the ADG
      produced at Fort Stewart to verify the methane content and com-
      pare it to the estimate.
   c. *Amount of hydrogen that could be produced.*
      Chapter 2 (page 11) estimated that the amount of hydrogen that
      could be produced by the fuel cell operating 2 hrs/day, 360
      days/year was equal to ~ 3.7M SCF/year. It would be helpful to ob-
      tain some measured data from the actual useable hydrogen pro-
      duced from a fuel cell that would validate this estimate.
   d. *Amount of Useable Hot Water (Cogeneration) Available.*
      Chapter 2 (pp. 10-11) estimated that a certain amount of heat in the
      form of hot water could be used for cogeneration purposes from the
      WTE-H_2-FC system in the WWTP. This assumes that heat from an
      existing boiler in the WWTP can be displaced at a certain rate. It
      would be helpful to verify that: (1) there is indeed an operational
      boiler at the WWTP at Fort Stewart, (2) verify the amount of fuel
      the boiler uses from boiler logs or other means.

4. ***Availability of Equipment / Alternatives.*** The type of system (Waste to Energy, hydrogen production fuel cell system [WTE-H_2-FC]) described in this report is not commercially available at this time. However, components of this system are commercially available and it is envisioned that with the proper integration and engineering the components could be combined with the necessary controls to produce the WTE-H_2-FC system in question. There are many questions that need to be addressed with regards to the cost, maintenance required, and lifetime of the proposed system, among others. Also, the feasibility of alternative systems that could perform a similar function as the WTE-H_2-FC should be explored.

5. ***Siting Requirements for the WTE-H_2-FC System***. Specific site requirements for the proposed WTE-H_2-FC system need to be addressed in the planning and design phase. These site requirements include but are not limited to: adequate space at the site for installing and maintaining the system, a nearby source of potable water for the fuel cell, a nearby source for the heat recovery integration and piping to use the waste heat from the system in the WWTP, etc.

6. ***Economics of Project***. Many assumptions throughout the report have been made with regards to the economics of the WTE-H_2-FC system. Given fairly accurate estimates of the amount and methane content of the ADG available from the Fort Stewart WWTP, the economics from the electric and thermal output of the fuel cell part of the system can be established to an acceptable degree of uncertainty, as many demonstrations of this type have been completed previously. However, the most dubious part of the economics of the WTE-H_2-FC system described in this report is associated with the hydrogen portion of the project. At Fort Stewart there is currently no use for the hydrogen expected to be produced from the WTE-H_2-FC system. A large amount of the savings of the project (~$120K/year) is based on the production of hydrogen, and its value if it were purchased commercially as opposed to being produced on site. This raises questions as to whether the economics from the hydrogen produced can really be included in the project economics. However, the availability of the hydrogen from the proposed project at Fort Stewart may induce an actual end use or application for the hydrogen. These questions and potential tradeoffs need to be identified, quantified, and resolved during the planning and design phase of this project.

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Appendix A: Estimated Model of ADG as a Function of MGD

The amount of Anaerobic Digester Gas (ADG) produced per day is a function of the Millions of Gallons of water treated per Day (MGD), the amount of organics contained, and the time the sludge stays in the digester. However, for most WWTPs, MGD is the most descriptive variable. Table C1 lists the results of a survey of 60 WTP conducted in Wisconsin and reported in "Anaerobic Digester Methane to Energy, A Statement Assessment." That data is used here to model the amount of ADG as a linear function of the MGD of through water. The fitted model is of the form Y=mX+b, where Y is the ADG/day, X is MGD and b is the intercept. The result of the regression is:

ADG (CF/Day) = 12,321 x MGD – 3,700

Table C2 lists the results of the linear regression. The high r2 value shows that the simple linear model is a good predictor of the amount of ADG produced by the MGD.

Table C1. Survey of 60WTP in Wisconsin.

Community	Current Flow MGD	ADG Production CF/Day	ADG Production CFM
1. Milwaukee-South-Shore-Plant*	100	1,260,500	875
2. Madison*	42	595,000	413.2
3. Appleton	14.9	386,200	268.2
4. Kenosha**	24	167,400	116.3
5. Racine**	29	148,000	102.8
6. LaCrosse	10	135,000	93.8
7. Neenah-Menasha*	9	130,000	90.3
8. Waukesha	9	129,600	90
9. Oshkosh	12	116,663	81
10. Sheboygan**	12	107,460	74.6
11. Beloit	6	101,250	70.3
12. Brookfield	8	79,770	55.8
13. Wausau**	5	75,000	52
14. Manitowoc	7.5	58,740	40.8
15. Sturgeon-Bay	1.5	57,600	40
16. HOVMSD*	5	52,122	36.2
17. Eau-Claire*	7	49,770	34.6
18. Beaver-Dam**	3	40,200	27.9

Community	Current Flow MGD	ADG Production CF/Day	ADG Production CFM
19. South-Milwaukee	3.5	39,540	27
20. Monroe	2	33,100	23
21. Richland-Center	1	35,205	24.1
22. Stevens-Point	3.1	30,240	21
23. Rib-Mountain	2.4	29,625	21
24. Watertown	3.5	29,423	20.4
25. Superior	3.28	29,900	20.8
26. Menominee	1.6	29,800	20.7
27. Burlington*	3.25	27,900	19.4
28. West-Bend	5	27,368	19
29. Oconomowoc	2.1	22,940	15.9
30. Sun-Prairie*	2.3	22,600	15.7
31. Waupaca**	1.1	22,000	15.2
32. Chippewa-Falls**	2.35	21,200	14.7
33. Grafton	1.278	20,940	14.5
34. Walcomet**	4.24	19,700	13.7
35. Waupun	1.5	19,500	13.5
36. Heartland-Delafield*	1.85	18,900	13.1
37. Jefferson	1.5	17,600	12.2
38. Whitewater	1.4	16,939	11.8
39. Port-Washington**	1.5	17,000	11.8
40. Two-Rivers**	2	16,900	11.7
41. Rice-Lake*	1.5	16,400	11.3
42. Stoughton	1.5	15,300	10.6
43. Merrill	1.2	14,400	10
44. Platteville	1	13,500	9.4
45. Plymouth	1.6	13,000	9
46. Marinette	2.3	12,000	8.3
47. Jackson	0.9	11,200	7.8
48. Algoma	1	10,900	7.6
49. Portage	1.5	9,850	6.8
50. New-London	1.2	9,600	6.7
51. Hudson	1.3	9,200	6.4
52. Black-Creek	0.5	7,500	5.2
53. Rhinelander	1.1	6,568	4.6
54. Mukwanago	0.7	6,700	4.6
55. Berlin	0.7	5,200	3.6
56. Kiel	0.6	5,600	3.9
57. Nekoosa	0.35	2,868	2
58. Cashton	0.1	1,800	1.3

Community	Current Flow MGD	ADG Production CF/Day	ADG Production CFM
59. Marathon	0.25	1,320	0.9
60. Augusta	0.23	1,250	0.9

Table C2. Regression analysis results.

Term	Value
Independent Variable	-3700
Slope	12321
Standard Error of Independent Variable	6433.65
Standard Error of Slope	415.428
Standard Error of Y Estimate	45568.43
r^2	.938137
F Statistic	879.5627
Degrees of Freedom	58
Regression Sum of Squares	1.8264E+12
Residual Sum of Squares	1.20436E+11

Appendix B: DD 1391 Suggested Language

Suggested DD 1391 Language Supporting Waste-to-Energy-Hydrogen Infrastructure-Fuel-Cell Project

> ***DATA FOR EACH BLOCK OF THE 1391 FOR INPUTING INTO 1391 PROCESSOR***

COMPONENT:	ARMY FY07 MILITARY CONSTRUCTION PROJECT DATA
DATE	16 SEP 2005
INSTALLATION AND LOCATION	Fort Stewart, GA
PROJECT TITLE	ELECTRICITY COST REDUCTION
PROGRAM ELEMENT	
CATEGORY CODE	813 20
PROJECT NUMBER	XXXXX
PROJECT COST	1,680
COST ESTIMATES	
PRIMARY FACILITY	1,515
Prime Power Plant Kw	600 2.50 (1,500)
Wiring/Grounding	(15)
SUPPORTING FACILITIES	
None	
ESTIMATED CONTRACT COST	1,515
CONTINGENCY PERCENT (5.00%)	75
SUBTOTAL	1,590
SUPERVISION, INSPECTION & OVERHEAD (5.7%)	86
TOTAL REQUEST	1,676
TOTAL REQUEST (ROUNDED)	1,680
ASSOCIATED CONSTRUCTION COST	(0)

Projection Description

> ECIP project to reduce the cost for electrical power at Fort Stewart, GA by: (a) shaving peak load power demand, and by (b) replacing power consumption throughout the year. This project will provide one 200kW generator fueled by Hydrogen gas recovered from the gas generated in the waste water treatment plant's anaerobic digester. Surplus hydrogen gas will be used for infrastructure purposes as the needs arise.

> REQ: 200 ADQT: NONE SUBSTD: NONE

Project Justification

This project is required to reduce the installation operating expenses related to the utilities ("J" Account) and to begin the use of a hydrogen gas based infrastructure.

A refurbished UTC Fuel Cells PureCell 200 kW PAFC and the balance of power generation plant needed to produce electricity from the by product gases of the wastewater plant at Fort Stewart will be installed. Work includes Hydrogen fueled fuel cells, with hydrogen purification system, and hydrogen storage and dispensing skid. This system will also begin the development of a hydrogen infrastructure to support emerging hydrogen powered fleets. An estimated savings of 10 cents/kWh for electricity was used in the economic analysis section of this 1391. Additional savings are estimated for thermal energy savings and for use of the excess hydrogen gas for infrastructure uses. The economic analysis shows a simple payback period of 7.6 years with a Savings to Investment Ratio of 1.74.

Additional Information

This project complies with current planning and design criteria. Cost savings for this project will be verified by validating monthly energy bills. Additional cost savings will be documented as use of the surplus Hydrogen generated is used for future infrastructure needs such as Hydrogen fueled vehicles. Points of contact on this project are Henry Gignilliat, OACSIM, Army ECIP Program Manager, 703-428 -7003 & Fred Louis, Fort Stewart, GA, 912-767-5034. All required physical security measures and Antiterrorism/Force Protection (AT/FP) measures will be implemented into this project's design & construction. An Economic Analysis (EA) was prepared using the NIST BLCC (ECIP) program and utilized to help evaluate this project.

Impact If Not Provided

Fort Stewart will continue to expend funds unnecessarily for power costs that can be saved by using gas generated by the waster water treatment facility. Also, as future demand for Hydrogen powered infrastructure occurs, the gas supply will not be ready.

Estimated Construction Start:	Jan 2008	Index: XXXX
Estimated Midpoint of Construction:	Mar 2008	Index: XXXX
Estimated Construction Completion:	Jun 2008	Index: XXXX

Quantitative Data

TYPE OF DESIGN:	This facility does not include unusual construction features That require extra design effort.
UNIT OF MEASURE:	KVA
A. TOTAL REQUIREMENT	200
B. EXISTING SUBSTANDARD	0
C. EXISTING ADEQUATE	0
D. FUNDED, NOT INVENTORY	0
E. ADEQUATE ASSETS	0

///AUTHORIZED FUNDED

H. DEFICIENCY (A-E)	200	200

Appendix C: NIST BLCC 5.3-05: ECIP Report

Economic Analysis of the Installation and Operation of a HyCoGen Energy Plant at Fort Stewart, GA for the Recovery of a Renewable Energy Source

This analysis is based on the assumptions that:

- The power plant will give 20 years of beneficial use.
- Power generation will occur 16 hours/day for 360 days/year.
- The analysis includes 10¢/kwh savings.
- The analysis includes $40,000/year of maintenance cost.
- The analysis includes thermal savings of $30,000/year.
- The analysis includes $120,000/year of income from Hydrogen produced.
- The expected life of cell stacks is 10 years and the replacement cost is $400,000.
- The analysis includes the cost of the hook up to the grid and the digester gas line.
- The analysis does not include the cost of extra gas lines or extra power lines to hookup the fuel cell to the anaerobic digester or to the electric substation because the substation is relatively close to the water treatment plant.

The analysis was done using the Building Life Cycle Cost (BLCC). Below is the ECIP report.

NIST BLCC 5.3-05: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2005.

Location:	Georgia		Discount Rate:	3%
Project Title:	Power generation at Fort Stewart using hydrogen generated from waste water treatment gases	Analyst:		Bob Neathammer
Base Date:	September 1, 2005	Preparation Date:		Thu Sep 15 13:02:48 CDT 2005
BOD:	July 1, 2008	Economic Life:		22 years, 10 months
File Name:	c:\program files\blcc5\projects\ analysisus- ing10centsand150000excessh2.xml			

1. Investment

Parameter	Cost
Construction Cost	$1,500,000
SIOH	$75,000
Design Cost	$0
Total Cost	$1,575,000
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$1,575,000

2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$29.30711	3,930.8 MBtu	$115,200	12.966	$1,493,643
Energy Subtotal		3,930.8 MBtu	$115,200		$1,493,643
Water Usage	$141952916299.63950	0.0 Mgal	$150,000	13.887	$2,083,106
Water Subtotal		0.0 Mgal	$150,000		$2,083,106
Total			$265,200		$3,576,749

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Annually recurring	-$40,000	Annual	13.887	-$555,495
Non-annually recurring				
Replace fuel cell stacks at year 10	-$400,000	10 years 0 months	0.744	-$297,638
Non-annually recurring subtotal	-$400,000			-$273,756
Total	-$440,000			-$829,251
4. First year savings	$207,678			
5. Simple Payback Period (in years)	7.58	(Total investment/first-year savings)		
6. Total discounted operational savings	$2,747,498			
7. Savings to Investment Ratio (SIR)	1.74	(Total discounted operational savings/total investment)		
8. Adjusted Internal Rate of Return (AIRR)	5.54%	$(1+d)*SIR^{(1/n)-1}$; d=discount rate, n=years in study period		

NIST BLCC 5.3-05: Input Data Listing

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

Parameter	Date
File Name:	C:\Program Files\BLCC5\projects\ANALYSISUSING10CENTSAND150000EXCESSH2.XML
Date of Study:	Thu Sep 15 13:04:12 CDT 2005
Analysis Type:	MILCON Analysis, ECIP Project
Project Name:	Power generation at fort Stewart using hydrogen generated from waste water treatment gases
Project Location:	Georgia
Analyst:	Bob Neathammer
Comment:	This analysis uses a flat $0.10 per kWh for energy savings and a 10-year stack life and annual savings of $120,000 for use of excess h2 gas produced
Base Date:	September 1, 2005
Beneficial Occupancy Date:	July 1, 2008
Study Period:	22 years 10 months (September 1, 2005 through June 30, 2028)
Discount Rate:	3%
Discounting Convention:	Mid-Year
Discount and Escalation Rates are REAL (exclusive of general inflation)	

Savings from Alternative: HYDROGEN FROM WASTE WATER TREATMENT TO POWER A FUEL CELL

Energy Savings/Cost: Electricity

Parameter	Data
Annual Savings	1,152,000.0 kWh
Price per Unit:	$0.10000
Demand Charge:	$0
Utility Rebate:	$0
Location:	U.S. Average
Rate Schedule:	Residential
State:	Georgia

Usage Indices

From Date	Duration	Usage Index
July 1, 2008	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2005	1 year 0 months	-2.25%
April 1, 2006	1 year 0 months	-3.44%
April 1, 2007	1 year 0 months	-2.52%
April 1, 2008	1 year 0 months	-0.76%
April 1, 2009	1 year 0 months	-0.58%
April 1, 2010	1 year 0 months	-0.41%
April 1, 2011	1 year 0 months	-0.05%
April 1, 2012	1 year 0 months	0.32%
April 1, 2013	1 year 0 months	0.86%
April 1, 2014	1 year 0 months	0.4%
April 1, 2015	1 year 0 months	0%
April 1, 2016	1 year 0 months	0.27%
April 1, 2017	1 year 0 months	0.76%
April 1, 2018	1 year 0 months	0.93%
April 1, 2019	1 year 0 months	0.53%
April 1, 2020	1 year 0 months	0.3%
April 1, 2021	1 year 0 months	-0.13%
April 1, 2022	1 year 0 months	-0.26%
April 1, 2023	1 year 0 months	-0.22%
April 1, 2024	1 year 0 months	0.39%
April 1, 2025	1 year 0 months	0.17%
April 1, 2026	1 year 0 months	0.04%

From Date	Duration	Escalation
April 1, 2027	1 year 0 months	0%
April 1, 2028	1 year 0 months	0.04%
April 1, 2029	1 year 0 months	0.04%
April 1, 2030	1 year 0 months	0%
April 1, 2031	1 year 0 months	0.04%
April 1, 2032	1 year 0 months	0.04%
April 1, 2033	1 year 0 months	0.04%
April 1, 2034	1 year 0 months	0%
April 1, 2035	Remaining	0.03%

Water Savings/Cost: THERMAL WATER SAVINGS

	Annual Usage			Annual Disposal
	Units/Year	Price/Unit	Units/Year	Price/Unit
@Summer Rates	1.0 L	$7500.00	0.0 L	$0.00
@Winter Rates	1.0 L	$22500.00	0.0 L	$0.00

Escalation Rates - Usage

From Date	Duration	Usage Cost Escalation
September 1, 2005	Remaining	0%

Escalation Rates - Disposal

From Date	Duration	Disposal Cost Escalation
September 1, 2005	Remaining	0%

Usage Indices - Usage

From Date	Duration	Index
July 1, 2008	Remaining	100%

Usage Indices - Disposal

From Date	Duration	Index
July 1, 2008	Remaining	100%

Water Savings/Cost: EXCESS H2 PRODUCED SAVINGS

	Annual Usage			Annual Disposal
	Units/Year	Price/Unit	Units/Year	Price/Unit
@Summer Rates	1.0 L	$30000.00	0.0 L	$0.00
@Winter Rates	1.0 L	$90000.00	0.0 L	$0.00

Escalation Rates - Usage

From Date	Duration	Usage Cost Escalation
September 1, 2005	Remaining	0%

Escalation Rates - Disposal

From Date	Duration	Disposal Cost Escalation
September 1, 2005	Remaining	0%

Usage Indices - Usage

From Date	Duration	Index
July 1, 2008	Remaining	100%

Usage Indices - Disposal

From Date	Duration	Index
July 1, 2008	Remaining	100%

Capital Component Savings/Costs

Additional Investment Cost

Parameter	Cost
Construction Cost:	$1,500,000
SIOH:	$75,000
Design Cost:	$0
Total Cost:	$1,575,000
Salvage Value of Existing Equipment:	$0
Public Utility Company Rebate:	$0
Total Investment:	$1,575,000

Annually Recurring Savings/Cost: ANNUAL MAINTENANCE COST

Amount Saved:	-$40,000
Annual Rate of Increase:	0%

Usage Indices

From Date	Duration	Factor
July 1, 2008	Remaining	100%

Non-Annually Recurring Savings/Costs: REPLACE FUEL CELL STACKS AT YEAR 10

Years/Months:	10 years 0 months
Amount Saved:	-$400,000
Annual Rate of Increase:	0%

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14. ABSTRACT
Volume I of this work represents a preliminary analysis of the economics from an anaerobic sludge digester Wastewater Treatment Plant (WWTP) at a military installation integrated with a fuel cell with hydrogen production capabilities. The waste-to-energy, hydrogen production/infrastructure development, fuel cell system (WTE-H2-FC) was submitted for FY06 Energy Conservation Investment Program (ECIP) funding based on the estimated Savings to Investment Ratio (SIR) range of 1.5 – 2, and an estimated Simple Payback Period of 8+ years. Volume II of this project will include a more detailed analysis that will validate the assumptions made in Volume I, and produce a planning and design document to be used to implement the WTE-H2-FC system. This analysis considered Army installations, future analyses of the application of this technology may include Air Force and Navy bases.

15. SUBJECT TERMS
fuel cells
wastewater treatment plants
WTE-H2-FC
Energy Conservation Investment Program (ECIP)
energy conservation

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